Final Report
Project No. A-394

X-BAND MICROWAVE RING SWITCH

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Contract No. DA-49-186-502-ORD-709
Diamond Ordnance Fuze Laboratories Project No. 52989
Ordnance Corps
Department of the Army

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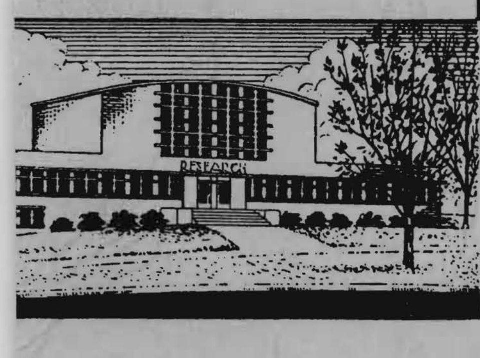
26 November 1958



Engineering Experiment Station
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ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology

Final Report
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X-BAND MICROWAVE RING SWITCH

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Object: Design and Development of an X-Band Microwave Ring Switch

26 November 1958

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ABSTRACT

This report describes an X-band microwave ring switch which was designed and developed at Georgia Tech for the Diamond Ordnance Fuze Laboratories under Contract No. DA-49-186-502-ORD-709.

This switch employs an offset junction which makes possible the low-loss wide-band characteristics of the switch. The theory of operation of the offset junction and the physical description and electrical characteristics of the switch are described.

X-BAND MICROWAVE RING SWITCH

Purpose of Contract

The purpose of this contract was to design and develop an X-band microwave ring switch with the following basic requirements:

1. Operating frequency range: 9.0 - 9.6 kmc
2. VSWR: less than 1.15 over the operating frequency range
3. Insertion loss: less than 0.3 db over the operating frequency range
4. Active sectors: three output arms spaced 120° apart and activated sequentially through an active sector of 70° with the position of the sector adjustable throughout a range of 150°
5. Power handling capability: 300 kw (peak) with 15 psig pressurization
6. Speed of rotation: 40 revolutions per minute
7. Life expectancy: 5000 hours (minimum) at operating speed of 40 rpm
8. Physical dimensions: input and output waveguide geometry to be compatible with existing DOFL equipment; switch to replace existing switch and rotary-joint without alterations to supporting structure that would prevent reinstallation of existing switch and rotary-joint
9. Mechanical design considerations: materials to be used to give optimum electrical characteristics; design to be such as to reduce stresses in the switch and in the supporting structure to a practical minimum
10. Switch to be constructed at Georgia Tech and installed in an existing system located at Aberdeen Proving Ground, Aberdeen, Maryland.

Introduction

The ring switch is a device for sequentially switching energy from a stationary waveguide into one or more circularly-moving waveguides; a section through a typical switch is shown in Figure 1. The basic structure consists of a ring waveguide which is split longitudinally to enable one portion to rotate with respect to the other. Although the switch is a bilateral device, the following description is written on the assumption that it is transmitting energy from a generator to a load, such as an antenna system. Microwave energy is coupled into the ring guide by the input junction which is attached to the stationary part of the switch. The energy flows through the ring guide until it reaches an output junction which is attached to the rotating part; here it is coupled out of the ring into an attached waveguide. Several output junctions can be attached to the rotating part of the ring switch; then, rotation of the upper section of the ring switch causes the energy to be sequentially switched from one output arm to the next.

To meet the requirement of having three output arms spaced 120° apart and activated sequentially through an active sector of 70° with the position of the sector adjustable through 150°, it was necessary to have two ring waveguides in the switch as shown in Figure 2. Rotation ofthe center section of the ring switch positions the active sector; rotation of the upper section of the switch sequentially activates each output arm as it passes through the active sector.

To meet the electrical requirements of the contract, the offset junction, which was developed at Georgia Tech, was employed for coupling energy into and out of the ring waveguides. A brief description of the junction is given in this report; a more detailed description will be published at a later date.

Physical Description

The ring switch is shown in Figure 3 (assembled) and in Figure 4 (disassembled). The sub-assemblies shown in Figure 4 were machined from yellow brass, soft-soldered together, and silver plated. In Figure 3, the three output arms can be seen on the top surface of the switch, and the input arm is partially visible at the bottom.

Figure 2 is an isometric section of the ring switch, shown with four output arms rather than three to show the junctions more clearly. The switch is constructed of three principal parts: Part A, the lower section, is stationary and its input junction is connected to a transmitter-receiver system (see Figure 5); Part B, the center section, can be manually rotated through an angle of 150 degrees to adjust the center of the 70 degree active sector; Part C, the upper section, rotates at 40 rpm.

Figure 6 is an orthographic section through the energy path of the switch; the dashed line represents the path followed by microwave energy as it propagates through junctions A, B, and C of the switch. As stated above, junction A is stationary, junction B is manually positionable through 150 degrees, and junction C, which is one of the three equally spaced output junctions, rotates at 40 rpm. As the switch rotates the energy is sequentially switched from one output junction to the next.

The mean radius of the bend D and the length of the taper E in Figure 2, connecting each of the switch junctions to the external waveguide, were designed to produce minimum practical VSWR.

Serrated chokes are used to reduce radiation loss through the gaps between the center section of the switch and the upper and lower sections (see Figure 4). These chokes are required only in the vicinity of the junctions; this is discussed under Offset Junction.

Offset Junction

The offset junction was developed at Georgia Tech under Contract Nos. DA 36-039 SC-72789 and DA 36-039 SC-52654. Its basic geometry consists of a junction cavity of length a and width b which is used as a coupling device between two rectangular waveguides as illustrated in Figure 7. The junction has a simple geometrical configuration which requires no additional matching devices. Since all discontinuities are parallel to the E-field, the performance is independent of the E-dimension.

In the junction cavity the width b, which is approximately 1.5 times the width of the coupled guides, is large enough for the propagation of both TE_{10} and TE_{20} modes; the junction impedance characteristics are the result of interaction of the energy in these modes. A rigorous theoretical analysis of the junction has not yet been completed; however, qualitative arguments can be given.

The offset junction is a bilateral device, but in this discussion, assume that the energy is being coupled from guide 1 into guide 2. At the discontinuity between guide 1 and the cavity, all modes are excited; however, only the TE_{10} and TE_{20} modes are above cutoff frequency. Consider the behavior of these two modes: the TE_{10} mode energy has a slower phase velocity than the TE_{20} mode energy; hence, the relative phase between them changes as they propagate down the cavity. In practice it has been found that, for best junction performance, the electrical length of the cavity, dimension a, must simultaneously be (n + 1) half-wavelengths long for the TE_{10} mode and n half-wavelengths long for the TE_{20} mode, where n is a positive integer. Thus, the total relative phase shift, including the cavity end effects, is π. This relationship is illustrated in Figure 8; notice that the boundary conditions at the ends of the cavity are roughly satisfied if the phase and amplitude of each mode are as illustrated.

Thus, it is seen that the width and length of the cavity are the important parameters in the design of the offset junction. The cavity width determines the velocity of each mode and, hence, their relative velocity or phase shift per unit length; the cavity length, including end effects, determines the total phase shift.

A qualitative explanation for the wide bandwidth characteristics of the offset junction can also be given. Assume that the junction dimensions are optimum for a particular frequency f_o; then a small increase of operating frequency will make the cavity length longer in wavelengths, but the TE_{20} mode phase velocity is decreased more than that of the TE_{10} mode. Therefore, the change in the total relative phase shift is small, causing little effect on the operation of the junction; a decrease in frequency produces a similarly small effect.

Figure 7 illustrates the manner in which the junction can be split for use in a ring switch. In this case, guide 2 represents the ring guide which is split down the center of the H-dimension. Since the currents in the guide walls are parallel to the split except in the junction cavity, chokes are required only in this region, and the loss in the split ring guide is almost as small as that in ordinary waveguide.

The ring guide for this switch was curved in the E-plane with a mean radius of 4.5 inches. The E-dimension was made 0.600 inch to increase power transmission capability and to reduce loss. Figure 9 illustrates the VSWR versus frequency for a typical offset junction of this configuration. The dashed lines indicate the frequency at which a resonant peak in the VSWR was calculated to occur. To prevent the occurrance of this resonant peak in the design band of the switch, it was necessary for the H-dimension of the ring guide to be 0.880 inch rather than the 0.900 inch of RG-52/U.

Switch Performance

Electrical measurements were made to determine the following three characteristics of the switch: voltage standing wave ratio, insertion loss, and power transmission capability.

The maximum VSWR was measured for representative frequencies over the operating band. The energy transmission path (see Figure 5) consisted of the input waveguide, the input taper, a 90° H-plane bend, the input junction, the center ring junction, one of the three output junctions, a 90° H-plane bend, an output taper, and the output waveguide terminated with a sliding load. The positions of the center ring and output ring were varied to give a maximum VSWR at each frequency. The higher VSWR with output arm number 1 is believed to be caused by a discontinuity in its output waveguide assembly; since, before the input and output waveguide assemblies were installed, the maximum VSWR from the switch was 1.12. The limited time available for the development of this switch did not allow time for additional tests and possible improvement.

The loss through the entire ring switch, including the input and output waveguides, was measured by the substitution method; the loss was found to be less than 1/4 db over the design band for representative switch positions.

The switch transmitted 200 kilowatts of peak power at atmospheric pressure without breakdown. Since this was the largest power source available for test purposes, the breakdown power could not be measured. With 15 psig pressurization, it is estimated that the switch will handle a peak power of more than 600 kw.

Approximately 45 degrees of switch rotation is required for switching between successive output arms; thus the maximum usable scan sector is approximately 75 degrees.

Conclusions and Recommendations

The waveguide ring switch which is described in this report is a low-loss broad-band device which satisfies the technical requirements of the contract. The characteristics of the switch are made possible by the use of the offset ring-switch junction.

To obtain a total switch loss as small as the specified 0.3 db, the E-dimension of the energy path inside the switch was increased from the 0.400 inch of standard X-band waveguide to 0.600 inch. This E-dimension could have been retained at 0.400 inch which would have eliminated the requirement for the tapers in the E-plane at the input and the outputs of the switch; however, the power loss in the switch would have increased slightly. Junction design is independent of the guide height (the E-dimension) in the switch if the length a of the junction cavity, as measured along an arc having the mean energy-path radius, is maintained constant.

A simplification in mechanical design and fabrication could be made by locating the serrated chokes only on the center section of the switch (see Figure 4); it would then be possible to electroform the upper and lower sections of the switch as integral units. This design change would reduce the required machine work and eliminate almost all of the soldered mechanical joints along the boundaries of the energy path.

Acknowledgements

The completion of this project was possible only through the combined efforts of many persons of the Georgia Tech Engineering Experiment Station and the Diamond Ordnance Fuze Laboratories.

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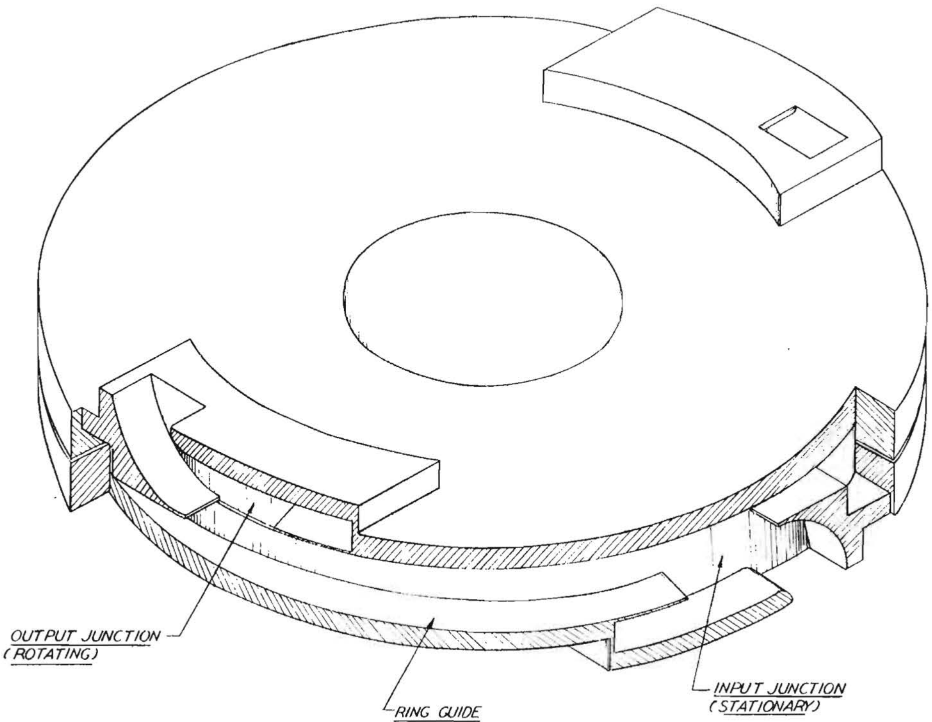

FIGURE 1
A SECTION THROUGH A TYPICAL RING SWITCH

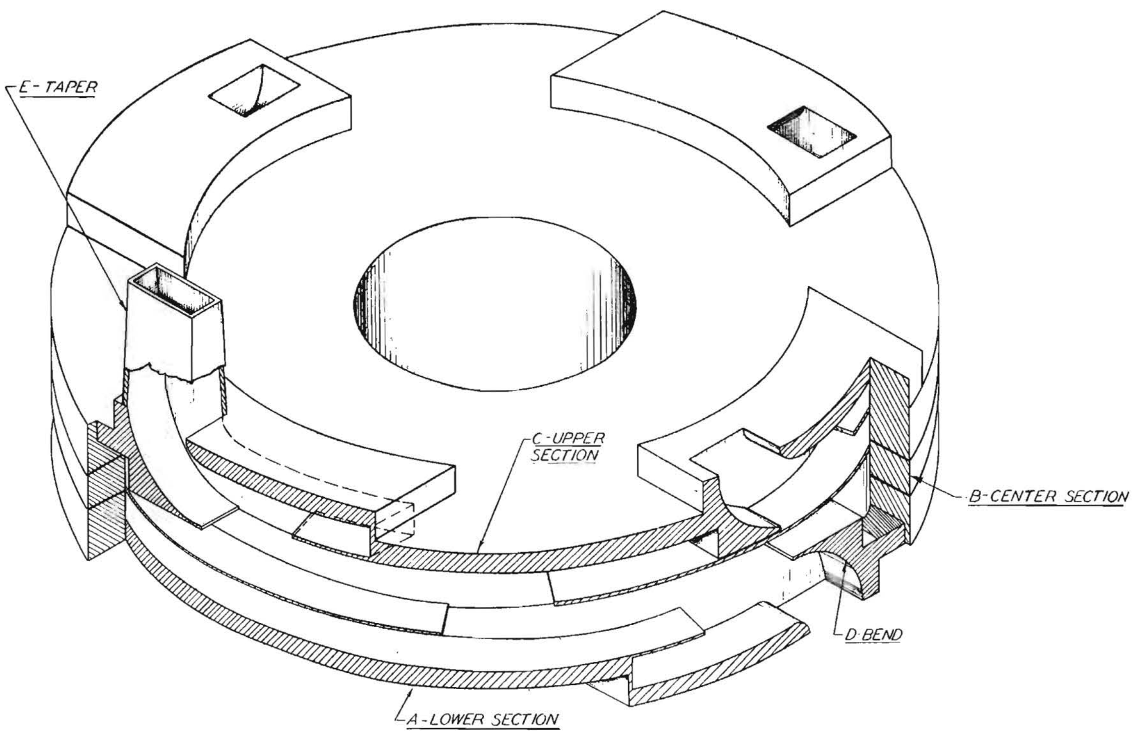

FIGURE 2
AN ISOMETRIC SECTION OF THE X-BAND MICROWAVE RING SWITCH
(SHOWN WITH FOUR OUTPUT ARMS, RATHER THAN THREE, IN ORDER TO SHOW JUNCTIONS MORE CLEARLY)

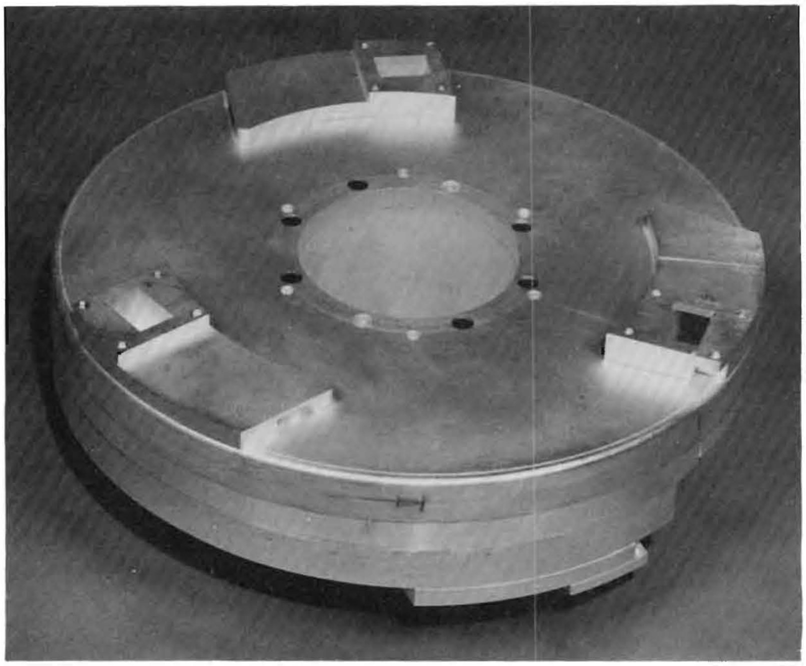

Figure 3. The X-Band Microwave Ring Switch (Assembled).

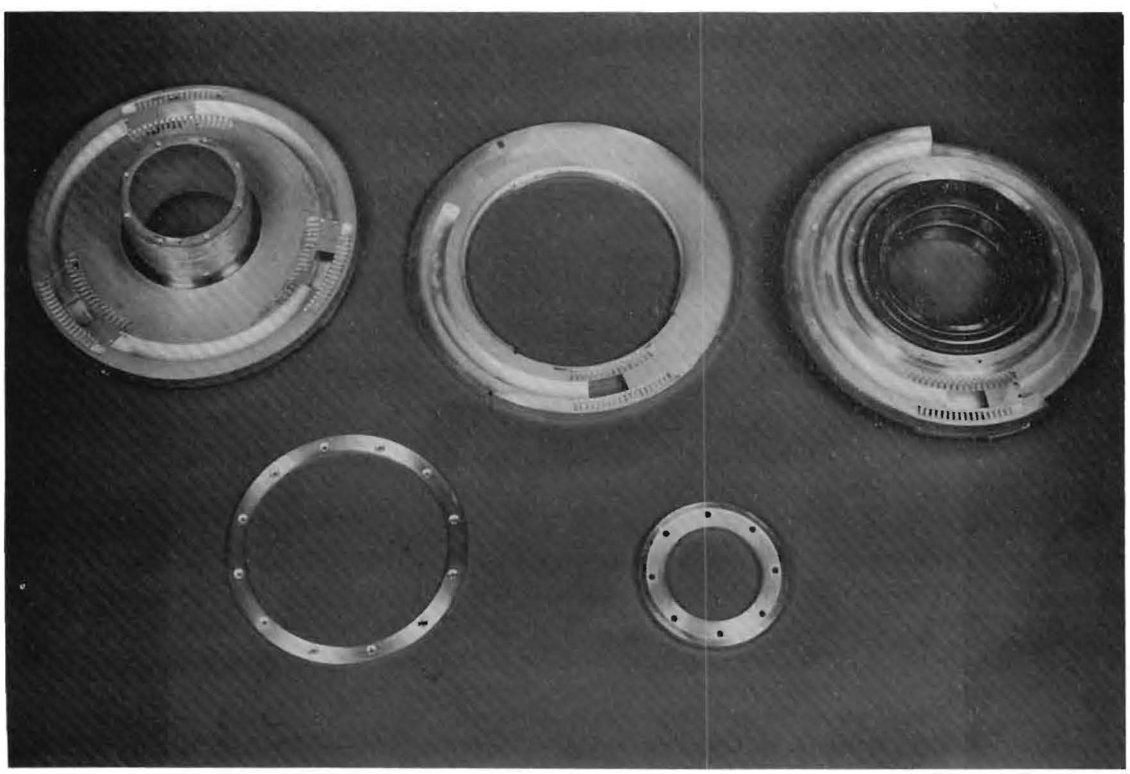

Figure 4. The X-Band Microwave Ring Switch (Disassembled).

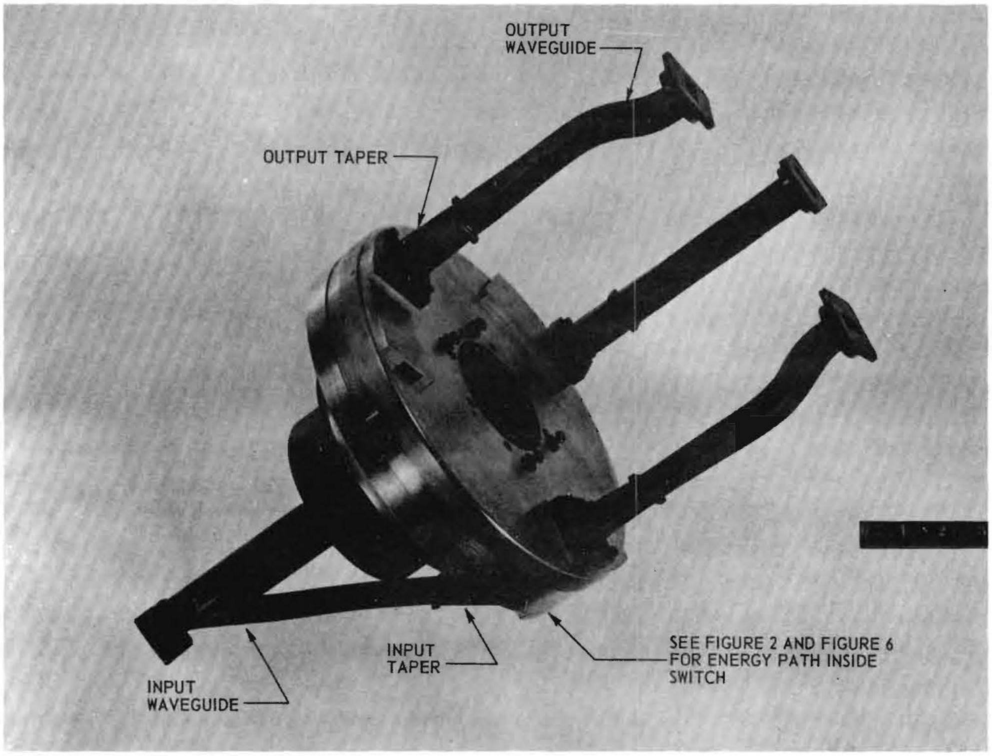

Figure 5. The Ring Switch and Connecting Waveguide Assemblies.

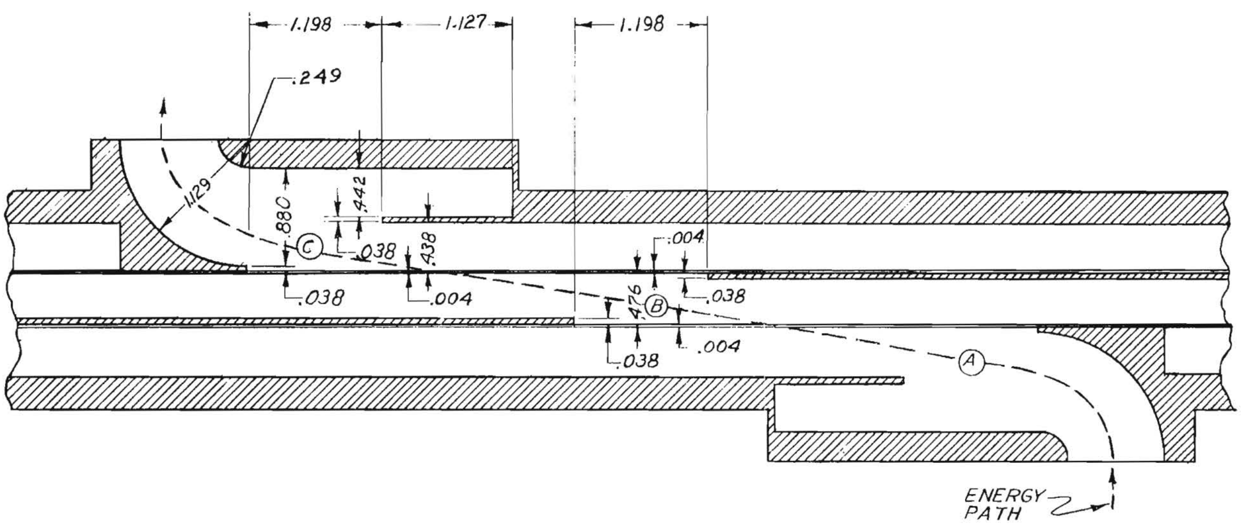

FIGURE 6

A SECTION THROUGH THE ENERGY PATH OF THE SWITCH

(THE JUNCTION A B & C ARE SHOWN)

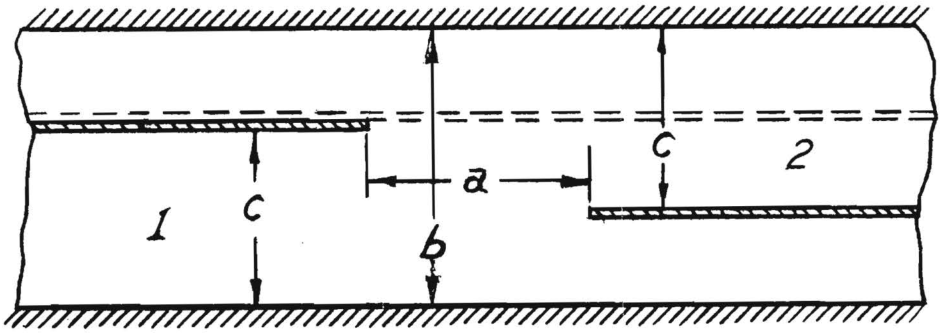

Figure 7. The Basic Geometry of the Offset Junction. The Width C is the H-Dimension of Guide 1 and Guide 2, (Note: The E-Field is Perpendicular to the Plane of the Page); The Dashed Lines Indicate Where the Junction Can Be Split for Use in a Ring Switch.

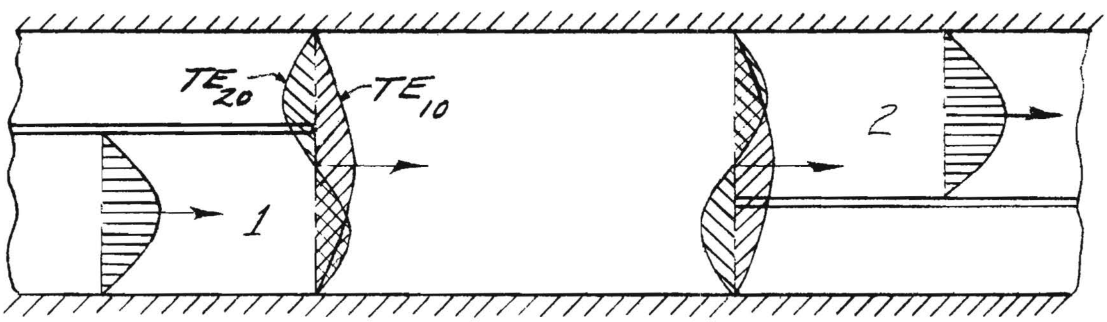

Figure 8. The Propagating Modes in the Offset Junction. The Curves Represent the E-Field Amplitude, and the Arrows Represent the Direction of Propagation.

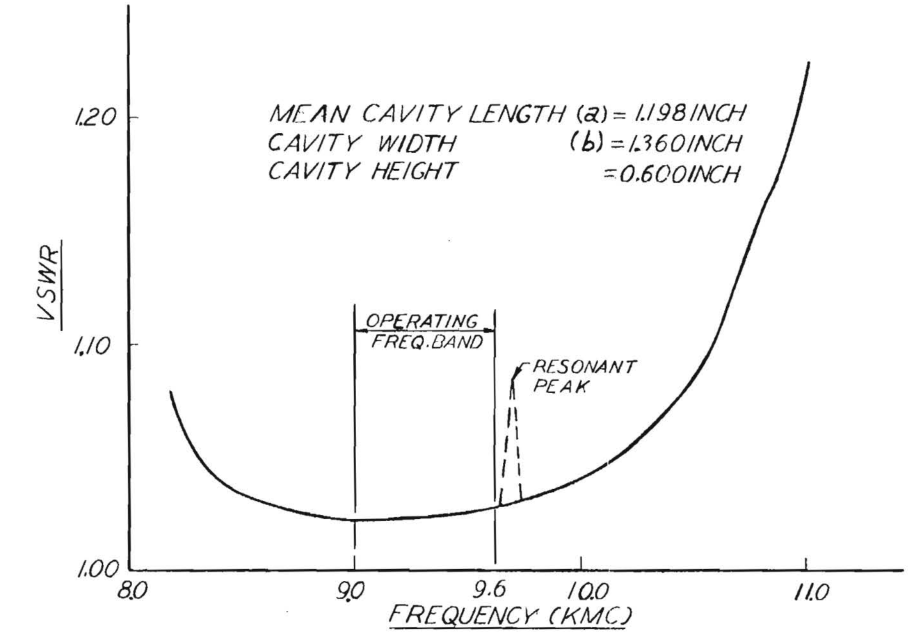

Figure 9. The VSWR Versus Frequency for a Typical Offset Junction. This Junction Had the Indicated Dimensions and Was Curved in the E-Plane with a Mean Radius of 4.5 Inches.

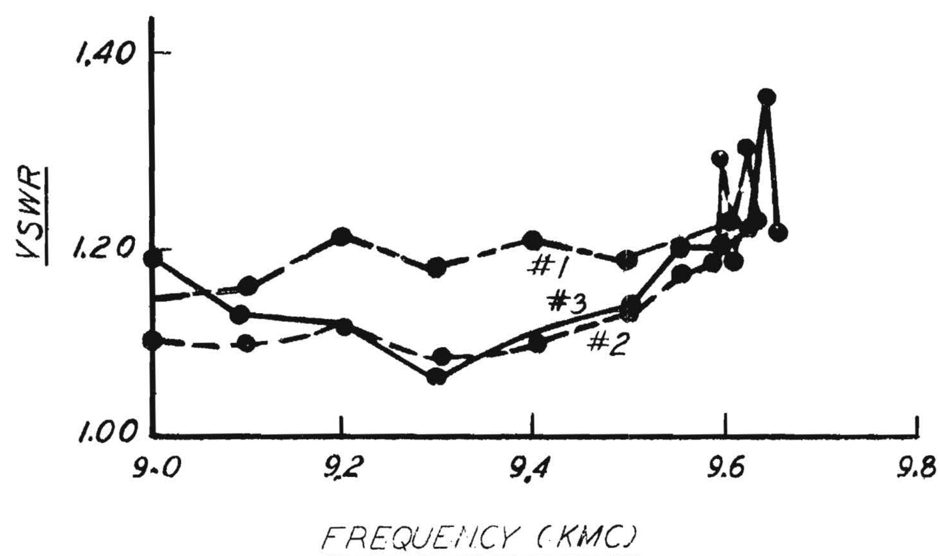

Figure 10. The Maximum VSWR Versus Frequency for Each of the Output Arms. The Energy Path Includes the Total Path Through the Ring Switch and the External Waveguide as Shown in Figure 5.